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by

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Abstract: Closely following the notion of innovative geographic clusters, this paper examines knowledge flows in the US agriculture industry for evidence of innovative agglomeration. The data indicate that a closer distance between any two agricultural patent origins increases the probability that one cites the other as prior art. Further, subtle interregional variations characterize the degree to which proximity advances agricultural innovation. Finally, the results show that older innovations in agriculture proliferate more readily than recently created knowledge.

Keywords: Innovation, Agriculture, Economic Geography, Patents

Introduction

Agricultural production dominates large segments of the US economy and technological advances are of increasing importance in this sector as they are in the larger economy. Nevertheless, the spatial diffusion of agricultural innovation is neither well-studied, nor well-understood. This study seeks to catalog farm technology and innovation in a geographic context. Closely following the notion of innovative hubs proffered by Jaffe et al. (1993), this study tests the US agriculture industry for evidence of innovative agglomeration. A rich body of literature finds evidence of geographic clustering in the economy as a whole (Jaffe et al., 1993; Audretsch, 1998; Gersbach & Schmutzler, 1999), though little evidence is offered on agriculture in particular. According to Shapira and Fuchs, clustering arises because the forces of labor market pooling, specialized local goods, and the efficiency of local knowledge networks encourage firms to gather spatially. Earlier work notes that the nature of aggregation may vary considerably from one industry to another, and it is possible that some industries do not cluster at all (Audretsch & Feldman, 1996; Valente, 1995). Whether or not agriculture may be characterized in this way remains to be explored.

Tracking knowledge networks has motivated many researchers to use patent data in tests for economies of agglomeration. Interestingly, patents and agriculture share a rich history. Before 1849, the United States Patent Office was a subsidiary of the Department of Agriculture. Griliches (1957; 1990), notes the usefulness of patents as economic indicators of innovation, especially in agriculture. Theoretical and empirical studies of such agglomerative behavior continue to be a subject of interest, such as Storper (2010), Kukalis (2010), Oyama (2009), Glaeser and Gottlieb (2009), Karscig (2009), and Knoben (2009). In general, the literature agrees that locating near likeminded business organizations represents a strategic decision on the part of the firm. Economies of agglomeration benefit the firm via increased worker productivity (Puga, 2010), increased sales owing to convenience (Jerwood and Parker, 1974), strategic partnerships in marketing (Lassila, 2006), supply chain logistics (Seabright and Weeds, 2007), and reduced input costs (Fuchs, 2003).

Bakos and Brynjolfsson (1999) show that economies of aggregation arise not only in markets of tangible goods, but also in the marketplace of ideas. That is, information goods can encourage geographic aggregation. According to Bakos and Brynjolfsson (2000) and Gallaugher et al. (2001), one key contributor to such agglomerative activity, including innovative clusters, is a low marginal cost structure. While marginal costs in agriculture are quite low, they are not emblematic of the marginal cost structure of agricultural innovation. In fact, Dupont (2009) observes that innovation in agriculture is quite costly, as evidenced by massive expansion in R&D funding from the United State Department of Agriculture in the past 40 years.

Audretsch (1998) and Valente (1995) note that the nature of aggregation may vary considerably from one industry to another, and it is possible that some industries do not cluster at all. This paper tests knowledge flows in agriculture by first spatially tagging each agricultural patent granted from 1972 – 2002 using Geographic Information Systems (GIS) software. The geostatistical results extend the long-standing belief that shorter physical distances lubricate innovation flows within in the agricultural sector. To the authors' best knowledge, no such study has appeared in the literature.

Literature Review

Arguments for and against geographic clustering in agriculture abound in the literature. Interregional variability of environment and the almost perfectly competitive nature of agriculture point to the presence of agglomeration. Still, low expected revenues and lack of financing, inadequate Intellectual Property (IP) rights, the agglomerative tendencies of urban areas, and the relatively long "half-life" of knowledge in the industry may splinter innovation geographically. If the latter effects offset the former, agriculture may offer an exception to the rule of clustering in the economy as a whole proffered by Jaffe et al. (1993).

Geoclimate Roadblocks

Agricultural innovations seldom result in nationwide adoption. Huffman (1998) notes that environmental peculiarities determine the usefulness of new technology in agriculture more than any other industry. These environmental factors include climate, soil, elevation, ocean influence, and continental air mass influence**.** The variability in environment inhibits large-scale diffusion of new technologies, which might be suited to a particular region but useless in another. For example, Griliches (1957) finds striking interregional differences between rates of acceptance of hybrid corn technologies.

Evenson (1989) termed these inhibitors to widespread use "geoclimate roadblocks." Geoclimate roadblocks intensify aggregation effects because inventors are likely to develop products that they can test in their own region. If innovators tailor their efforts to a particular climate zone, then their creations would cite prior art, probably from the same climate zone, which in turn cited prior art, probably from the same climate zone, and so on. In that sense, geoclimate inhibitors can intensify citation networks within regions of common climates.

Near-Perfect Competition and Innovation

Competitive market conditions drive innovation, and if any industry approximates perfect competition, it is agriculture (Encaoua and Hollander, 2002). Homogeneity of crops and animal products, an abundance of buyers and sellers, and relatively weak barriers to entry characterize the industry. According to Porter (2000) and Simmie (2004), the allure of finding a cost-cutting advantage in such competitive market conditions compels innovation.

The irony is that perfect competition leaves farms with the drive to innovate, but without the resources. Since perfectly competitive firms break even long run, improving technology can bring short term gains only, regardless of whether the innovator maintains exclusive rights or sells them. Still, the short-term rewards are incentive enough to innovate. According to the U.S. Office of Technology Assessment (1995), the promise of monetary gains – however ephemeral they may be – induces innovation in agriculture.

While competition may drive innovation, the exact degree of competition in agriculture is debatable. The Herfindahl-Hirschman Index (HHI) for the steer, heifer, and hog markets, for instance, exceed 1800, and are therefore considered “highly concentrated” markets, while other markets such as crops conform to the “near-perfect competition” assumption many follow for agricultural economics. The HHI in many of those industries is well below 1000. Fortunately, whether market power in the sector is diluted or concentrated should not affect incidences of clustering since economies of agglomeration arise wherever there is competition. For instance, in the model by Maldonado-Berenguer et al. (2005), a game theoretic market of as few as two firms engaged in Cournot competition resolves to equilibrium in which both firms aggregate at the center of the city.

Long “Half-Life’ of Knowledge and Innovation

Sectors that resist technological change deter innovators from producing new technologies. According to Perez (2002), their innovations will face limited demand, if any, because most actors in the industry simply do not buy new technology. Jaffe and Trajtenberg (1996) note that sectors amendable to rapid technological changes, such as the electronics or semiconductor industries induce densely packed, localized citation networks.

The literature debates the extent to which agriculture accepts technical change. Adam Smith (1776) famously conjectured that inherent challenges in the division of farm labor restrict technical revolutions, and the assumption of relative stagnancy in agricultual technology has permeated studies as recent as Matsuyama (1991). An examination by Ruttan (2002), however, finds that by the latter half of the nineteenth century, the focus of the agriculture industry had shifted from increasing the quantity of natural resources to maximizing the efficiency with which those resources were cultivated. This transformation led to a science-based agriculture, which is more amenable to technological progress than once thought. Martin and Mitra (2001) confirm that the rate of productivity growth in agriculture actually surpasses that of manufacturing, citing heavy R&D investments in agriculture over recent decades as a likely cause. The portrait of knowledge in agriculture by Huffman (1998) offers a realistic middle ground. He describes agricultural know-how as slow to change, but not static.

Urban density and innovation

Carlino (2007) notes that all else equal, a city with twice the jobs per square mile of another city will show 20 percent more patents per-capita. These findings are confirmed by Kerr (2010), who notes that cities experience significantly higher patent growth rates than rural areas. Population growth induces capital investment, leads to infrastructure development, and allows new markets to emerge. Each of these factors in turn encourages technological innovation (Pender, 1998).

Intuition suggests that the observed connection between urbanity and a rapid transmission of ideas may not apply to agriculture. This intuition finds support in an analysis by Griliches (1957), who notes that rates of acceptance of hybrid corn technology are higher in states with relatively low urban populations. For example, Iowa, Indiana, and Illinois showed the highest rates of acceptance for the new agricultural technology, while New York was one of the states with the lowest rates of acceptance.

Low Expected Revenue and Lack of Financing

Low expected revenues and a lack of financing plague R&D in agriculture. Mankins (2009) notes that inherent unpredictability of events such as frost, drought, and pest infestation reduces expected revenues for the farm industry. These risks make it difficult for firms to create bold development strategies. The threat of going bankrupt at any time because of external factors is indeed enough to discourage innovation. High levels of unpredictability in the industry also make it hard for firms to acquire financial backing for research. After all, lenders know that agricultural enterprises, faced with sufficiently unfavorable environmental circumstances, will default on their loan repayment.

R&D in agriculture is also unique because, according to Plato (1988), it takes the "nothing ventured, nothing gained" mentality and flips it on its head. In agriculture, the saying should be "nothing gained, everything ventured." This idea finds more recent support in Roucan-Kane et al. (2007), who note that profit margins from previous years are *negatively* correlated with the R&D undertaken the following year. Good years do not motivate farmers to invest in innovation, but bad years do. These patterns, observe Rosenzweig and Binswanger (1993), may owe in large part to the finding that bad years motivate farmers to invest in R&D in an effort to prevent further losses. However, it is precisely the bad years that discourage lenders from financing R&D in agricultural firms (Pederson and Zech, 2009).

The nature of financing in the agricultural sector is also noteworthy because public research rivals private research. While private research expenditures have surpassed public research expenditures in agriculture since the 1950s, Fuglie (1996) notes that R&D among private farms pales in comparison to R&D endeavors in the economy as a whole. Roucan-Kane et al. (2007) add that R&D expenditures with respect to sales have even declined in the industry over the last 17 years.

Johnson and Evenson (1999) point out that government financed R&D plays a more prominent role in agriculture than in other industries. Such high levels of government-financed research, according to Terleckyj (1980), impede productivity growth and technological change. If government-financed research does actually impede technological change, then the data should reveal relatively low patent growth in agriculture compared to the general economy, all else equal.

Inadequate Intellectual Property Rights

For years, agriculture has suffered from disjointed intellectual property rights. Atkinson et al. (2003) posit that until recently, the state of IP laws in agriculture prevented any single institution from acquiring a complete set of rights as to ensure freedom to operate (FTO) with a particular technology. Terleckyj (1980) finds that strengthened IP rights are emerging in the private sector, but that they have certainly not caught up with IP rights in the general economy. This fragmentation of intellectual property rights in agriculture in turn fragments innovative activity.

To mitigate this problem, The Public Intellectual Property Resources for Agriculture project, or PIPRA, was launched in 2003. The endeavor marks the joint effort of 14 universities and plant research centers to help innovators navigate issues of intellectual property and commercialization (Boettiger and Bennett, 2007). Whether or not PIRPA amplifies innovative activity in the long run, the fact that it was necessary in the first place suggests that IP rights in private agriculture needed strengthening. Barriers to IP rights in agriculture splinter innovative activity geographically. Such innovative dispersion comes in stark contrast to industries outlined by Lindmark (2007) such as publishing, communications, renewable energy, health care, and entertainment, for which stable IP rights promote spatial agglomeration.

Data

This study examines the diffusion of agricultural innovation, as proxied by patent citations. Specifically, the model aims to explain the probability of citation through the following explanatory variables: patent stock, R&D per capita in the state where the citing/cited patents were granted, time between citations, and distance.

For clarity, the present study considers patent classes that fall within the "Agriculture and Farming" grouping defined by the US Patent and Trademark Office. Table 1 presents a list of those categories and the corresponding patent classes.

Table 1: Agricultural Patent Classes

US Patent Class	Class Description
99	Foods and beverages: apparatus
426	Food or edible material: processes, compositions, and products
111	Planting
166	Wells
449	Bee culture
452	Butchering
43	Fishing, trapping, and vermin destroying
47	Plant husbandry
119	Animal husbandry
54	Harness
56	Harvesters
59	Chain, staple, and horseshoe making
168	Farriery
231	Whips and whip apparatus
131	Tobacco
239	Fluid sprinkling, spraying, and diffusing
426	Food or edible material: processes, compositions, and products
504	Plant protecting and regulating compositions
147	Coopering
71	Chemistry: fertilizers
256	Fences

Source: United States Patent and Trademark Office, "US Patent Classes - Chemical Group: Agriculture and Farming." Available at www.ibiblio.org/patents/chgroup.html, accessed 12/01/09.

The unit of analysis considered in this study is the likelihood of citation between two agricultural patents granted in the United States between 1972 - 2002. The citation data was obtained from the United States Patent and Trademark Office (USPTO), as was the data on grant years, and assignee addresses. The population data was obtained from the US Bureau of Census and the figures for state levels of research and development were obtained from the archives of the National Science Foundation. Each of the variables is described below and Table 2 provides descriptive statistics of the sample.

Distance

Geographic Information Systems (GIS) software was used to geocode each address based the *x* and *y* coordinates of the city corresponding to each address. The USPTO citation database provided instances of prior art relationships, to which the *x* and *y* coordinates were assigned to each location, that of the citing patent and that of the cited patent. From this, the Cosine-Haversine distance formula offers a way to find the distance between the two points of the citation relationship. If one point is (x_1, y_1), another point is (x_2, y_2), and the radius of the earth in kilometers is R, then the somewhat unwieldy Haversine formula :

$$Distance = 2\mathrm{R}\ \mathrm{atan2}\left(\sqrt{\sin^2[(x_2 - x_1)/2] + \cos(x_1) * \cos(x_2) * \sin^2[(y_2 - y_1)/2]}, \sqrt{1 - (\sin^2[(x_2 - x_1)/2)] + \cos(x_1)\cos(x_2)\sin^2[(y_2 - y_1)/2)]} \right) \quad (1)$$

gives the distance in kilometers between them (Robusto, 1957).

This formula measures distance “as the crow flies” over the surface of the earth, thereby capturing geographic distance more realistically than a Euclidian measurement, which would give the straight-line distance between two locations through the core of the earth. The expression atan2(a,b) is the two-argument arctangent function which gives the degrees in radians between the positive x-axis and the point (a,b). Equation (1) was used to generate the distance variable for the model estimation.

Probability of Citation

Estimating a probit model of the likelihood of citations requires data entries not only for successes, or prior art citations, but also for failures, or instances of potential citations that never materialized. Given a patent pool of size *n*, the combinatoric formula

$$C(n,k) = \binom{n}{k} = \frac{n!}{k!(n-k)!} \tag{2}$$

gives the number of potential citations between any *k* patents. Some of these potential citations materialize into prior art citations, but most do not. The data contain *n* = 36,328 distinct agricultural patents, and each potential citation consists of *k* = 2 patents. Therefore the number of potential citations within the agriculture patent class is

$$\binom{36328}{2} = \frac{36328!}{2!(36328-2)!} = \frac{1.2080407802 \times 10^{149890}}{2(9.153992924 \times 10^{149880})} = 659{,}843{,}628\,. \tag{3}$$

Over the period considered, 245,282 citations materialized in the agricultural class. To test whether those citations were propelled forward in some way by physical distance, some of the remaining 659,598,346 potential citations, which never materialized must be considered as well. The inclusion of event successes (extant citations) and event failures (potential but nonextant citations) is analogous to the original failures and successes appearing in one of the first applications of the probit method, which interestingly was developed in agriculture to test whether certain pesticides contributed to event successes (plant longevity) or event failures (plant death). A total of 20,011 of instances of event failures were added to the citation database as non-extant citations, or event failures, to accompany the 245,282 citations, or event successes, for a total sample size of 265,293.

R&D per Capita

Using population data directly from the US Bureau of Census and figures for state levels of research and development from the National Science Foundation, the figure for publicly funded research and development for each state was simply divided by the corresponding state population.

Time Gap

The time gap variable measures the span of time between the grant of the citing patent and the cited patent. The grant year of the cited patent, provided by the USPTO, was subtracted from the year of the corresponding citing patent for each prior art citation.

Patent Stock at Time of Citation

The measure of patent stock at the time of a citation was calculated as simply the total number of patents available for citation in the year of the grant of the citing patent. While this calculation uses the entire universe of patents as a point of reference, changes in the stock of agricultural patents are proportional to those of the general patent stock. As such the impact of using the entire universe of patents should not differ from the impact of a patent stock measure utilizing solely agricultural patents.

Table 2: Summary Statistics

	Average	Standard Dev.	Minimum	Median	Maximum
R&D per capita in cited state (dollars per person)	297.6	287.0	2.42	198.3	3040.1
R&D per capita in citing state (dollars per person)	286.8	385.3	2.42	175.4	6674.3
Time Gap (years)	7.8	6.5	0	7.0	27.0
Patent Stock	118667.7	33793.5	50177.0	104317.0	167438.0
Distance (km)	186.2	323.1	0	49.0	5268.0
					n = 265,293

Measurement Issues

One issue arising from the data is imprecision bias. Most Geographic Information Systems (GIS) software can give latitudinal and longitudinal coordinates only to the city level for the available patent data, and estimating proximity at the city level can lead to errors. For instance, two patents taken out in

Colorado Springs may be located anywhere within the 185 square miles that comprise the city (US Census Bureau, 2010a), yet the variable describing the distance between them evaluates to 0. To address the implications of imprecisely measured distance variables, Alibrandi and Waldfogel (2008) suggest that patent researchers aggregate years to increase sample sizes and consider multiple patent classes in industry-wide analyses. The data prepared for this study heeds both of those recommendations.

The time gap variable is also somewhat sensitive to imprecision bias. The time gap between one patent taken out in December and one patent taken out the January immediately following registers as one year, while the time gap between two patents taken out in January and December of the same year evaluates to zero years, despite the longer time gap in the latter case. This minor shortcoming notwithstanding, the metric does provide a reasonable, albeit somewhat fuzzy, measure of the time elapsed between the granting of two patents.

The same imprecision issue emerges in the patent stock variable. One patent taken out on December 31, 1999 and another taken out January 1, 2000 essentially face the same patent pool, but the patent stock variable on each of those patents would be different. The growth rate of agricultural patents has been fairly steady over time, so no measures of patent stock between consecutive years vary wildly. This steady growth helps rationalize the use of a patent stock variable at the annual level, although the measure is admittedly somewhat imprecise.

Model and results

In order to determine whether distance matters in agricultural innovation, the model that follows explores the probability that a citation network exists between two patents, *K* and *k*, controlling for the size of the patent pool, per capita levels of R&D in citing/cited states, and the time between patent grants. Incorporating the methodology of Jaffe et al. (1998), the model to be tested can be written as the estimated equation:

$$p_{k,K} = \alpha + \beta_1 S_k + \beta_2 \frac{RD_k}{Pop_k} + \beta_3 \frac{RD_K}{Pop_K} + \beta_4 T_{k,K} + \beta_5 D_{k,K} + \varepsilon \quad (4)$$

where $p_{k,K}$ is the probability that patent *k* cites patent *K* as prior art,

S_k is the total patent stock available at the time when patent *k* was granted,

$\frac{RD_k}{Pop_k}$ is the amount of per capita R&D in the state where patent *k* was granted,

$\frac{RD_K}{Pop_K}$ is the amount of per capita R&D in the state where patent *K* was granted,

$T_{k,K}$ is the difference in time between the years patents *K* and *k* were granted,

$D_{k,K}$ is the distance between the origins of patents *k* and *K*,

α and $\beta_i, 1 \le i \le 5$ are the intercept and slope parameters, respectively,

and ε is an error term.

Table 3: Regression Results

				n = 265,293 Pseudo R^2 = 0.2819		
	Coefficient	Standard Error	Z-Stat	95% Confidence Interval		Marginal Effect (Elasticity)
Constant	1.844413	0.017774	103.77 **	1.809576	1.879249	-------
Distance	-0. 0001217	2.80e-06	-43.45**	-0.0001272	-0.0001162	-8.69e-06
Time Gap	0.138921	0.0009117	152.38**	0.1371341	0.140708	0.0099214
Patent Stock	-7.84e-06	1.39e-07	-56.40**	-8.12e-06	-7.570e-06	-5.60e-07
R&D per capita in cited	11.0844	16.30874	6.75**	-26.29221	16.357420	7.861963
R&D per capita in citing	-4.967398	1.88021	-0.46	78.11989	142.049000	-0.3547595

** indicates statistical significance at the 95% level

Distance

According to Table 3, agricultural innovation depends on distance in a meaningful way, though the size of the effect is very modest. The negative and statistically significant distance coefficient shows that the clustering effects posited by Jaffe et al. (1993), Audretsch (1998), and Gersbach and Schmutzler (1999) exist in agriculture as they do in the economy as a whole. The finding suggests that the forces which facilitate agglomerative economies of innovation are strong enough to offset the previously mentioned impediments to clustering, such as the long half-life of agricultural knowledge, low expected revenues, and inadequate intellectual property rights. The elasticity with respect to distance states that the probability of two patents sharing a prior art relationship decreases by 0.000000869% for each additional percentage point in the distance between the two patent origins. For illustrative purposes, a patent is 0.000000869% more likely to cite a patent 100 kilometers away than it is to cite a patent 101 kilometers away, a single percentage change in distance. The meagerness of the marginal effect of distance suggests that proximity does not increase the probability of citation significantly, but instead increases the probability of a citation relationship somewhat delicately.

Time Gap

Similar to the distance in space between two patent origins is the distance between them in time. It makes intuitive sense that innovators would focus their efforts on improving relatively new innovations rather than working with dated innovations as prior art. The positive and significant marginal effect of the time gap, however, turns this intuition on its head. That is, the more time elapsed between the granting of two patents, the *more* likely it is that a prior art relationship exists between them.

This somewhat counterintuitive relationship between time gap and probability of citation in agriculture seems anomalous. Indeed the notion of older innovations receiving more citations contrasts with the negative correlation found between instances of citation and time gap by Choung Jae-Yong, et al. (2000), Csárdi (2007), and Narin and Olivastro (1993) in other industries. The difference probably owes to the greater technological complexity and relative infancy of the pharmaceutical and high-tech industries considered by those studies. That is, it is possible that innovations in the pharmaceutical and high-tech industries tend to draw upon recent breakthroughs, while innovations in agriculture draw upon traditional, enduring innovations.

Another possibility still is that the time needed for agricultural information to spread is longer in agriculture than in other industries, meaning that agricultural innovators experience a greater lag in encountering and improving upon new technologies. It is not hard to imagine that knowledge in the high-tech industry diffuses more quickly than knowledge in agriculture, owing to the rapid and ubiquitous modes of information exchange inherent in the technology sector. A similar argument could be made for pharmaceuticals. This scenario would suggest that by the time a patent is granted, the innovation being cited as prior art is fairly old, while more recent agricultural innovations have yet to gain the prominence to serve as prior art for profitable improvement.

Analysis of Distance by Region

The natural extension of national analysis is analysis by region to determine whether distance matters more in some regions relative to others. That is, are there some locations in which proximity to other innovators alters the probability of a citation, and other locations for which proximity alters the probability of a citation to a lesser extent, or not at all? Perhaps there are even regions for which close proximities *decrease* the probability of citation. To answer this question, probit regressions were run for each of the five major regions of the US as roughly outlined by the United States Census Bureau (2010b): the West, the Midwest, the Southwest, the South, and the Northeast. The t-scores in Table 3 test the distance coefficients for each subregion against the distance coefficient for the nation as a whole.

An important feature of Table 3 is that the upper bound on the 95% confidence interval for the United States and each subregion is less than zero. This result implies that regardless of subregion, closer distances imply greater probabilities of citation. Thus, the theoretical components of economies of agglomeration from Smith (1776) and Marshall (1890), along with the empirical findings of Jaffe (1993), Audretsch (1998), and Gersbach and Schmutzler (1999), all find support at the national and regional levels. Innovation in agriculture tends to cluster spatially, and it clusters regionally within the US.

Table 4: Distance Coefficients by Region and t-Tests against National Statistic

	Distance Coefficient	95% Confidence Interval		t-stat
United States	-0. 0001217	-0.0001272	-0.0001162	–
West	-0.0001181	-0.0001306	-0.0001056	1.11
Southwest	-0.0000935	-0.0001514	-0.0005570	1.55
Midwest	-0.0001090	-0.0001243	-0.0000938	2.20**
South	-0.0001979	-0.0002091	-0.0001868	-14.85**
Northeast	-0.0000918	-0.0001045	-0.0000791	5.20**

** indicates statistical significance at the 95% level

Of the five regions considered in Table 4, three distance coefficients depart from the national figure with statistical significance, although the variations are quite modest. These regions are the Midwest, the South, and the Northeast. In the Midwest and Northeast, distance matters less than in the country as a whole, while in the South, distance matters more. Specifically, relative to national likelihoods, patents from increasingly greater distances are less likely to be cited by Southern patents, and more likely to be cited by Midwestern and Northeastern patents. Several other studies regarding distance and innovation, such as Nunn and Worgan (2002), Paci and Usai (2009), and Gumbau-Albert and Maudos (2009), recognize the variability between regions in the degree to which distance impacts innovation. Varga (1999) notes that for the period 1972-1992, patent growth rates in the South are 79%, while growth rates in the Midwest and Northeast are only 52 and 45% respectively. Co (2002) confirms those regional trends.

Apart from growth rate explanations for innovative trends in the South, one explanation, and an avenue for further inquiry, includes the prevalence of large plantations in the old South. Massive plantations dominated agricultural exports in the United States until the end of the Civil War 150 years ago. Perhaps throughout the extensive history of agriculture in the South, the flows of information there evolved and adapted, leading to the elevated intensity of geographic clustering observed in that region.

Figure 1: Per Capita Citations Received and Citations Made by State for Agricultural Patents

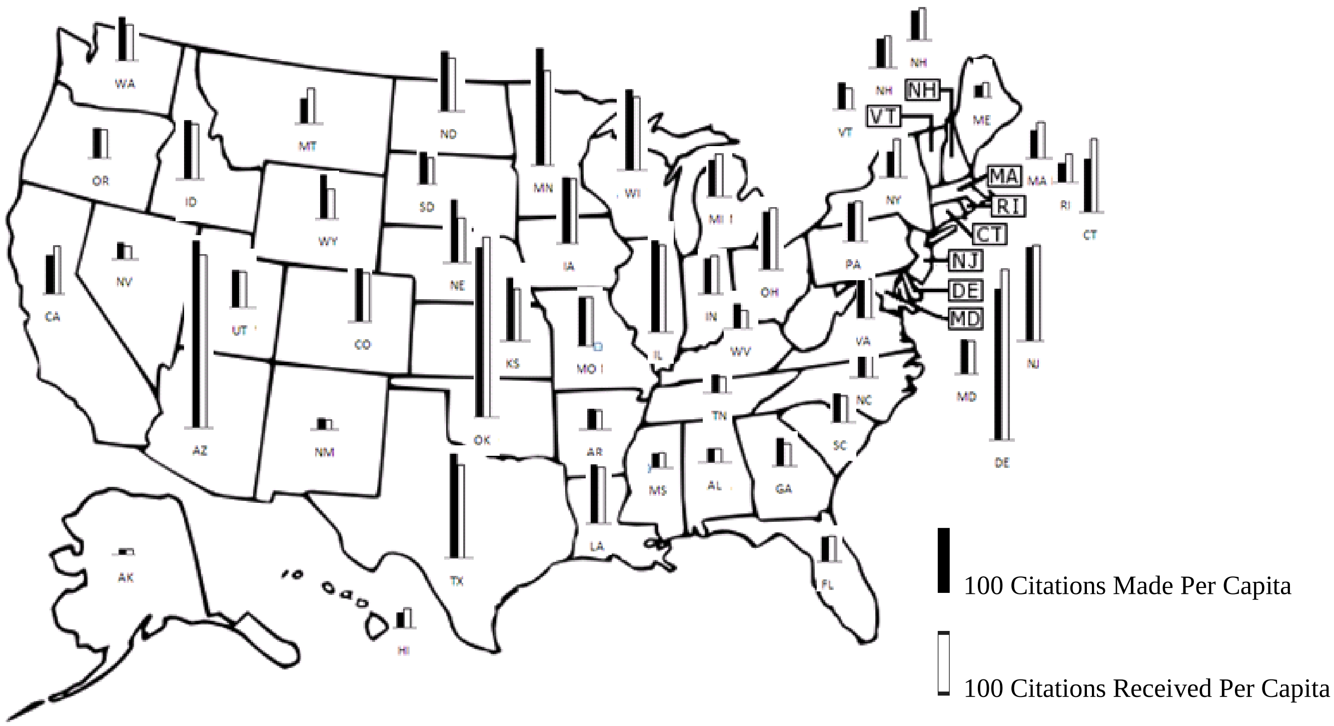

Figure 1 shows the volume of per capita citations made and received for each state. Typically, states which receive many citations also make many citations, and vice versa for states which make relatively few citations. Such a pattern suggests that areas prone to citing other agricultural patents are in turn prone to being cited themselves. Berkun (2007) refers to these hubs as hotbeds of innovation. Interestingly, regions where distance matters more and patents from more distant regions are less likely to be cited, such as the South, are not necessarily innovative hotbeds. Despite being a region in which distance most powerfully influences citation, and where innovative growth is rapid, the South is not a hotbed of agricultural innovation. In fact, relatively few innovators cite patents originating in the South. Therefore innovations in the South, rather than being improved upon by future innovators, tend to fizzle out relative to other regions of the US. Figure 1 shows the measly citation activity both to and from most southern states relative to the rest of the nation. Conversely, the Midwest and Northeast, areas where distance matters less and patents from more distant regions are more likely to be cited, show high levels of citations both to and from those areas. Taking the results from Table 4 and Figure 1 together, it is possible that distance matters more in regions where citation levels are high, and less in regions where citation levels are low. Alternatively, it may be that larger numbers of citations necessarily draw upon more patents, including those from greater distances.

Given the interregional differences in innovative activity, an exploration of the locations of hotbeds of agricultural innovation naturally follows. The states with the highest levels of citation per capita are Arizona, Oklahoma, Delaware, Minnesota, and Texas. One possible theory to explain the high levels of innovation in those areas is that they each lead the nation in some facet of agricultural sales. The value of commodity sales from vegetables in Arizona, for instance, ranks third in the country, and the state is the second largest seller of lettuce nationally (United States Department of Agriculture 2009a). Such high levels of vegetable production, as well as the lengthy history of ranching in Arizona outlined by Sayre (1999), may contribute to that area being a hotbed state. Similarly, in Oklahoma, sales of wheat, forage, and cattle each ranks within the top ten percent in the nation according to the USDA (2009b). While agricultural sales in Delaware hover around the national median (United States Department of Agriculture 2010c), Badertscher (2010) notes that farmers in Delaware have historically been major players in the nation's soybean and poultry markets. The United States Department of Agriculture (2009d) also describes farmers in Minnesota as the nation's number one sellers of turkey and sugar beet and third largest sellers of hogs and pigs. Finally, the cattle inventory in Texas, a state renowned for its ranching activity, outnumbers the national average by a factor of 7 (United States Department of Agriculture 2009e).

Conversely, the states with the lowest citation counts per capita are Nevada, Alabama, Mississippi, Maine, and Alaska. Climate conditions in Maine, Alaska, and Nevada are unfriendly to agriculture, which explains low agricultural production in those states and in turn may explain low innovative activity there. Mississippi presents something more of an enigma; According to the Mississippi Department of Agriculture and Commerce (2010), the number one industry in that state is agriculture, employing more than a quarter of the Mississippi labor force either directly or indirectly. The same anomaly surfaces in Alabama, a state in which agriculture constitutes one of the four major industries along with mining, forestry, and commercial fishing (Petersen 2010). The cases of Mississippi and Alabama show that the joint conditions of being in a region where distance matters more (i.e. the South) and producing agricultural goods and services in abundance do not necessarily give rise to hubs of innovative activity in agriculture.

Conclusion

This study finds that the role of distance in agricultural innovation is significant. Closer proximity between two patents increases the probability of citation between the two, while greater geographic distance impedes such citation relationships. The results show that in the Midwest and Northeast distance is less of a barrier to knowledge diffusion than in the nation as a whole. In contrast, analysis of the Southern states reveals that distance is a more significant barrier to information flows and the likelihood of a citation relationship decreases with increasing spatial distance. This study however does not the implications of differential knowledge flows across these regions. It would be valuable to follow this analysis with a study to determine whether greater knowledge diffusion among some regions is also accompanied by greater productivity gains over time.

This study confirms that the tendency for innovative activity to aggregate in the general economy also dictates the nature of the agricultural economy. In addition, the results indicate a unique relationship in agriculture between the age and proliferative capacity of an idea. Specifically, the more time that has elapsed since an innovation was created, the more likely it is to be cited as prior art by future innovators. This result contrasts starkly with the findings in other industries. It is unclear whether this results from barriers to the diffusion of new agricultural knowledge, the maturity of the agricultural industry, or other unidentified factors.

Admittedly, this study makes no attempt to measure the relative importance of individual patents and therefore cannot consider whether the diffusion of the knowledge codified in more valuable patents is inhibited by distance. Given the importance of the agricultural sector and the significant level of government involvement (extension services, crop support programs, international protectionism), there may be a role for government intervention to ensure the rapid diffusion of the most significant innovations. We leave this as an avenue for future work.

In sum, this study demonstrates the importance of distance in the diffusion of agricultural innovation. Innovative activity tends to aggregate within the wider economy, as well as within the agricultural sector. However, the extent to which agricultural knowledge diffuses, as proxied by patent citations, varies in important ways across the different regions of the United States. These findings raise interesting questions about the importance of knowledge flows across different crops and types of livestock, as well as the implications for industry productivity.

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